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CONTROL OF STEEL CORROSION IN CONCRETE SEA STRUCTURES

By
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Synopsis: Under the combined effects of exposure to ocean environments and heavy structural loading there are a number of deteriorating processes taking place. Experiences from the field have shown, however, that it is the electrochemical corrosion of the reinforcing steel which represents the greatest problem to the durability of concrete sea structures. Experiences have also shown that it may take a long time before any practical problems due to steel corrosion occur. When the problems do occur, however, the most susceptible parts of the structures are those parts which are the most exposed to intermittent wetting and drying in the splashing zone. A brief survey of protective methods indicates that it may be difficult to find a general method to inhibit this corrosion. However, if the steel corrosion is detected at a very early stage by a regular monitoring of steel potentials along the concrete surface, it should be possible to choke down and control the corrosion by application of a proper surface coating. In the long term the most direct way to reduce the problem of steel corrosion would be to develop new types of reinforcing materials which are less subjected to corrosion.

Keywords: admixtures; cathodic protection; chlorides; concrete durability; concretes; corrosion; corrosion resistance; deterioration; loads (forces); marine atmospheres; permeability; protective coatings; reinforcing materials; reinforcing steels; sea water; structural analysis.

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INTRODUCTION

All the literature on durability of concrete in sea water makes up a comprehensive, interesting and fascinating chapter in the long history of concrete technology. Concrete in sea water is a topic which has concerned professional people, committees, and national authorities through generations. A number of papers have been presented to international meetings such as The International Association for Testing Materials in Copenhagen 1909, New York 1912, and Amsterdam 1927, and the Permanent International Association of Navigation Congresses (PIANC) in London 1923, Cairo 1926, Venezia 1931, and Lisbon 1949. In more recent years there has been the meetings of The International Union of Testing and Research Laboratories for Materials and Structures (RILEM) in Pragh in 1961 and 1969, and the RILEM-PIANC meeting in Palermo in 1965.

As early as 1923 Atwood and Johnsen (1) had assembled a list of approximately three thousand references, and even today the discussion continues on the mechanism of deterioration of cement pastes in sea water (2). However, with the concrete technology of today it should not be the disintegration of the concrete itself which represents the greatest problem to the durability, but rather the electrochemical corrosion of the reinforcing steel (3). In the following, therefore, a brief survey will be given of various means to control this corrosion.

CORROSION OF REINFORCING STEEL

Concrete normally provides to embedded steel a high degree of protection against corrosion. This is because steel in concrete is polarized anodically, and a thin protective film of gamma iron oxide is formed on the steel surface. However, this passivating film is disrupted when the pH-value of the moisture in equilibrium with the concrete is reduced by carbonation, or when sufficient salt (chloride ions) has penetrated to the steel surface. The relationship between the rate of steel corrosion and the alkalinity and chloride concentration in the environment has not been completely elucidated. However, the works of Shalon and Raphael (4) and Hausmann (5) suggest that there is a threshold concentration of chloride ions which must be exceeded before any corrosion occurs. This threshold concentration of chloride ions depends on the pH-value.

It is a well known phenomen that even very small concentrations of chloride ions are able of breaking the passivating film. Bäumel and Engell (6) have shown that if a saturated calcium hydroxide solution substitutes the concrete, chloride concentrations even smaller than 0,0035 per cent have some effect on the passivity.

That the passivity of the steel becomes partly or completely broken only means that the electrochemical potential locally becomes more negative (anodic areas), while other portions of the steel still having the passivated potential intact thereby will act as cathodes and catchment areas for oxygen. Since moist concrete is a good electrolyte a rather complicated system of galvanic cell activity can develop along the steel. The electromotive force in these galvanic cells depends mainly on the pH-value and chloride concentration in the moisture next to the steel and on the transfer of dissolved oxygen through the concrete cover.

Depending on exposure, thickness of concrete cover, and age of concrete the following conditions may exist along the embedded steel:

- Moisture in equilibrium with uncarbonated concrete without any chlorides.

- Moisture in equilibrium with carbonated concrete without any chlorides.

- Moisture in equilibrium with uncarbonated concrete contaminated with chlorides.

- Moisture in equilibrium with concrete being both contaminated with chlorides and having low pH.

Normally, carbonation of concrete is not a problem unless cracking of the concrete has occurred or the concrete cover is defective. In high chlorine environments such as ocean environments, however, investigations on existing structures (7, 8) as well as on laboratory specimens (9) indicate that chloride ions can penetrate even into high-quality concrete to greater depths than what is normally prescribed as the thickness of concrete cover. However, this does not neccessarily mean that a severe steel corrosion will occur. When steel corrodes in concrete this is normally a process controlled by the rate at which dissolved oxygen can reach the steel. Thus, if the concrete cover is sufficiently thick or if the concrete is completely water saturated, this may slow down the transfer of oxygen and hence the rate of corrosion.

Even though some degree of steel corrosion has been reported on concrete piles continuously submerged (7) comprehensive observations in the field indicate that corrosion normally becomes more negligible if the concrete is continuously water saturated (8). The most susceptible parts of the structures are those parts which are the most exposed to intermittent wetting and drying (in the splashing zone). To control this corrosion a number of protective methods have been suggested and partly also applied.

PROTECTION OF REINFORCING STEEL

Cathodic protection

As long as a good electrolyte exists in the concrete, cathodic protection of the steel should always be possible. This type of protection is generally accomplished by connecting the steel to a source of electrons and then flooding the steel with a high concentration of electrons. The practical application may be effected in two ways, viz. by impressed polarization from an external generator, or by galvanic action from a bimetallic coupling (cfr. zinc on steel). Cathodic protection based on the generator method has been applied for some time on both ordinary reinforced and prestressed concrete structures (10, 11). The main problem from a practical point of view is to obtain control of potentials and current densities over the entire reinforcement. As the electrical resistivity of the concrete is highly dependent on the moisture and salt content in the concrete, the electrolytical conditions may noticeably vary from part to part within the same structure, as well as from time to time depending on the environmental conditions. Further, the applied voltages must not be too high, since excessive alkali may then lead to softening and breakdown of the bond between the steel and concrete. In recent years some criteria have been reached for application of cathodic protection (12). However, at the time being the practical experiences are very limited.

Choking of oxygen

Since corrosion of steel in concrete is normally of the oxygen type, the simplest way to inhibit corrosion should be to choke off the access to oxygen. For methods based on this principle it is important that the choking is equally effective to all the steel which is in electrical contact. Partial choking of oxygen may only promote formation of cell action.

As already mentioned transfer of oxygen will be slowed down by water filling the pores. An experimental attempt to prevent corrosion in this way has been described by Stratfull (10), where a number of wetting units were attached to the bottom surface of a bridge deck.

Sealing of the concrete surface by a proper surface coating will also effectively reduce the access to oxygen. Furthermore, this sealing will reduce the absorption and evaporation of moisture during changes in the weather conditions and thus promote more uniform moisture content in the concrete. On the other hand a coating will also involve a certain amount of maintenace. A defective coating may only promote formation of cell action.

Inhibiting admixtures

Suitable reagents added to the fresh concrete can develop various kinds of protective surface films on the steel. Several admixtures of this type have been investigated. However, from a practical point of view attention should be paid to the different behaviour of the different types of such admixtures. Thus, filming inhibitors of the anodic type are only effective when present in sufficiently high concentrations and are otherwise dangerous since the corrosion then will be intensely localized and the attack stimulated. Even though good experiences have been obtained by the use of corrosion inhibitors in concrete, such admixtures still should be used with some caution until more fundamental research is done.

Coating of the steel

Apart from chemical conversion coatings, where the metal is protected by its own oxide (phosphate coating), a number of non-metallic as well as metallic coatings have been suggested and partly applied as protective coatings for reinforcing steel. For the non-metallic coatings preparation of the steel surface by pickling and cleaning is necessary, and the bond to the concrete must also be secured. However, if such coatings should suffer mechanical damage, which may occur during handling of the steel, metal and hydroxyl ions will be able to pass between anodes and cathodes because no inhibitor is present, thus ending up in local corrosion.

If on the other hand the coating is of a metallic character, both a more efficient protection can be obtained as well as a rougher handling of the steel tolerated. The degree of protection will depend on the following factors:

- The polarity of the steel-metallic coating couple.
- The polarization characteristics of both the metallic coating as well as of the steel.
- Formation of macrocells on the metallic coating as a result of different environments along the surface of the metal.

Zinc has been applied for some time as a coating metal for reinforcing steel (galvanizing) (13). Since opinion has varied as to the efficiency of this coating, <u>Bird and Strauss</u> (14) did also investigate some other metal coatings such as high purity tin, copper, cadmium, nickel, and lead. According to these tests only zinc or cadmium could offer some protection. However, since the tests showed that the zinc itself rapidly corroded once salt had penetrated the concrete, it seems that a galvanized coating could postpone the onset of steel corrosion, but it would not delay its occurrance for a very long time. The same tests further showed that a coating of cadmium remained passive even in the presence of a high salt content in the concrete. It seems therefore that cadmium could offer a good protection, but it may be argued that both the price and the toxic properties of this metal would make such a coating less attractive.

CONCLUDING REMARKS

It should be pointed out that depending on the thickness and quality of the concrete cover it may take a long time for the salt to reach the steel. Also, the presence of salt in the concrete is only one of several factors necessary for a steel corrosion to occur. Experiences from the field indicate that a number of structures have been a long time in service without any problems due to steel corrosion (15). However, since there are so many factors involved, it may be difficult to predict a period free of corrosion for one particular structure based on experiences from other structures. As a consequence all larger structures for which the safety plays an important role, should be periodically monitored for any changes in steel potentials from the passive to the active state. By measurements of steel potentials along the concrete surface it should be possible to detect a steel corrosion at an early stage before any cracking or spalling of the concrete would occur.

The problems involved with a surface coating were previously pointed out. However, if a steel corrosion is detected at a very early stage a further steel corrosion could possibly be choked down by application of a proper coating to the concrete surface. The corrosion of the steel would then be controlled by the efficiency of the sealing and the maintenance of the surface coating.

In the long term the most direct way to reduce the problem of steel corrosion would be to develop new types of reinforcing materials which are less subjected to corrosion. On the background of the rapid development taking place in the use of reinforced concrete in ocean environments the development of such materials should be a matter of increasing importance.

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SHOTCRETE COVERCOATS FOR PRESTRESSED CONCRETE TANKS

By
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Synopsis: The author provides a brief history of the original use of shotcrete to provide corrosion protection for spirally wound prestressed shotcrete and concrete tanks. In addition, various failures are described along with reasons for the failures. Details are also given of steps that must be taken to insure permanent corrosion protection for the wire.

Keywords: circular prestressing; corrosion resistance; domes (structural forms); failure; prestressed concrete; reinforcing steels; roofs; shells (structural forms); shotcrete; spiral reinforcement; tanks (containers).